June 14, 2005

The Palomar QUEST Variability Survey

A White Paper Submitted to the NSF-NASA-DOE Dark Energy Task Force

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ABSTRACT

The Palomar QUEST Survey is a sky survey concentrating on time variability studies. It uses the 1.3 m Samuel Oshin Schmidt Telescope and the Palomar Observatories of Cal Tech (the P48) with the Large Area (4^o x 4^o) Yale-Indiana QUEST CCD Camera. The survey, expected to last 5 years, plans to cover 15,000 square degrees to a magnitude limit of ~ 21, with each area of the sky repeated 10 to 20 times with time intervals between scans varying from minutes to days to months to years up to 5 years. This rich data set will serve a dozen or so different science projects, at least four of which will have some relevance to the investigation of Dark Energy:

1. A Study of low redshift Type Ia Supernovae, called the Nearby Supernova Factory
2. A study of Type II Supernovae to determine to what extent they can be calibrated to be standard candles.
3. A study of Strong Lensing of Quasars using a large homogeneous sample of lenses.
4. A study of intermediate redshift ($0.1 \leq z \leq 0.3$) Type Ia Supernovae.

1. Introduction

The Palomar QUEST Project uses the Samuel Oshin Schmidt Telescope (the P48) at the Palomar Observatory with the QUEST Large Area Camera. The Project started routine data taking in September of 2003 and is being carried out by a Consortium consisting of the Yale-Indiana group, Cal Tech, and the Jet Propulsion Lab (JPL). The Project utilizes 100% of the time of the P48 telescope and uses follow-up time on the other Palomar telescopes. All of the data taken is available to all members of the consortium and their collaborators. However, within the larger consortium a number (10 or so) of smaller collaborations have formed to study different science topics. These groups and their topics of interest are summarized in Table 1. Many of these topics are not relevant to the study of Dark energy, but some of them, such as the type Ia and Type II Supernova Studies and the Strong Lensing of Quasars, are relevant.

The discovery and spectroscopic study of a large sample of low redshift Type Ia Supernovae is the discovery part of the Nearby Supernova Factory, with the Yale group in collaboration with S. Perlmutter, Greg Aldering and group from Berkeley and several French groups. This project is described in a separate White Paper entitled “The Nearby Supernova Factory”, G. Aldering, et al, submitted to the Dark Energy Task Force. For the sake of avoiding duplication this project will not be discussed in detail in this White Paper – the reader is asked to refer to the “Nearby Supernova Factory” White Paper.

This report will give a brief description of the Type II Supernova study and the study of the Strong Lensing of Quasars.

2. Description of the Palomar QUEST Project

The Palomar QUEST Survey uses the 1.26 m aperture Samuel Oshin Schmidt Telescope (the P48) of the Palomar Observatory with the Yale-Indiana Large Area QUEST Camera. This Camera, shown in Figure 1 (C. Baltay, et al, 2005), is located at the prime focus of P48, and is the instrument in use 100% of the observing time of this telescope. The camera has a mosaic of 112 CCD devices, each 600x2400 of 0.87” pixels, covering an area of 3.6^o by 4.6^o on the sky. Some of the properties of this instrument are summarized in Table 2.

The plan for the next few years is to operate the Palomar QUEST instrument about 50% of the time in a Point and Track mode, primarily for the JPL Near Earth Asteroid (NEAT) search, and the other 50% of the time in a Driftscan mode, primarily intended for quasar and SNe studies. The SNfactory intends to use both of these data sets for SNe discovery. The Point and Track mode uses typically 60 second exposures with a broadband red filter. During any given night the same area of sky is observed three times at approximately 30 minutes spacings for a total coverage of ~ 700 square degrees each night. In the Driftscan mode the effective exposure time is ~ 140 seconds and in each scan each star passes sequentially in front of four color filters, typically Johnson U,B,R,I. A 4.6^o wide strip, or a total of ~ 500 square degrees, is looked at in a good night. The same 500 square degree strip is scanned on the following night. In the Point and Track mode ~ 20,000 square degrees of sky have already been scanned and archived, and in the Driftscan mode ~ 15,000 square degrees have been scanned and archived. These will serve as the reference scans in the SNe search as well as the data to start the quasar survey for gravitational lensing studies. The new repeated scans (3 exposures at half hour spacing for Point and Track and two scans with 24 hour spacing for Driftscan) will serve as the discovery scans (New l, New 2, etc.). The requirement that SNe candidates appear in both New 1, New 2 discovery scans will greatly reduce backgrounds due to cosmic rays, asteroids, and other moving objects (airplanes, etc.).

In both observing modes the Palomar QUEST data comprises ~ 50 gigabytes/night of compressed Fits files (the Driftscan data is broken up into CCD size frames so both data streams are quire similar). This data is transmitted from the Palomar Mountain via a 48 Mbs radio link to the San Diego Supercomputer Center and from there via ESNET to CalTech, Yale and Berkeley LBNL and NCSA (Univ. of Illinois), where the data is archived. The reference scans are already located in this archive. At the present time a night's data is transferred in a few hours, so that the search for SNe's can start essentially the morning after the observations.

The bulk processing of the data is carried out at NCSA in an automated fashion, using the Yale driftscan data reduction pipeline. An independent pipeline, aimed at pixel level data coaddition and subsequent analysis is under development at Caltech. Also under development is a scheme to transfer data from Palomar Mountain in real time and a new fast pipeline for near time discovery of various types of transients and highly variable sources (Mahabal, et al (2005)).

The archiving and public data distribution of the PQ data will be fully NVO-compliant. A publicly accessible archive will be hosted at Caltech. PQ is the first major digital sky survey designed in the VO era, and it is in many ways a testbed and a precursor for the LSST and PanSTARRS (see Graham, et al (2004)).

3. Study of Low Redshift Type Ia Supernovae (the Nearby Supernova Factory)

The goal of this study is to collect a large sample of 300 Type Ia Supernovae in the redshift range $0.03 \leq z \leq 0.08$. This data sample will be a very important part of the large future high z supernovae experiments like CFHTLS, ESSENCE, and JDEM/SNAP by a) providing the low z anchor or calibration to the Supernova Hubble diagram (the high z experiments will not be able to obtain significant samples of $z \leq 0.1$ SNe's), and b) by taking 15 repeated spectra of each supernova as it develops, this sample will provide a unique study of the systematics of Type Ia SNe that will be crucial in gaining confidence in the results of these future experiments. Thus this part of the Palomar QUEST project is the most relevant one toward the study of Dark Energy and preparing for the future high precision supernovae experiments such as JDEM/SNAP. As mentioned in the Introduction above, this part of Palomar QUEST is the discovery engine of the "Nearby Supernova Factory", with the Yale group in collaboration with Saul Perlmutter, Greg Aldering and group at Berkeley and several French groups, and has been described in a separate White Paper to the Dark Energy Task Force entitled "The Nearby Supernova Factory" by G. Aldering, et al. We will therefore not discuss it any further in this White Paper but refer the reader to "The Nearby Supernova Factory" White Paper.

4. Study of Type II Supernovae

The luminosities of Type II Core Collapse Supernovae vary greatly, depending, among other things, on the mass of the parent star. There has been a suggestion (Hamuy and Pinto 2002) that there is a correlation between the peak luminosity of the Type II p supernovae and the expansion velocity of their photo spheres (see Figure 2). This correlation could be used to calibrate these SNe's to be useful standard candles and thus provide another method to study cosmological parameters such as the properties of dark energy. The goal of the Type II Supernova study of the Palomar QUEST Survey is to collect a sample of 20 to 30 SNe Type II to confirm (or otherwise) this correlation and to estimate how well their luminosities can be calibrated by this method.

With the magnitude limit of 21 of the Palomar QUEST Survey we can expect to discover Type II SNe up to a redshift of $z = 0.1$. We estimate that there will be about 20 such SNe in an area of 1,000 square degrees in a 15 day discovery window. The identification of SNe candidates will use the same process that we plan to use for finding Type Ia SNe for the Supernova Factory and is described in more detail in the Nearby Supernova Factory White Paper referred to above. Figure 5 shows one of the first few supernovae we found by this method. Since the Type II are typically fainter than the Type Ia at the same redshift, we expect the detection efficiency for the Type II to be lower, probably in the vicinity of 50%. The light curve of these SNe are quite different from the Type Ia – they have a rapid rise followed by a relatively flat plateau about 100 days long. We will use the UBRI colors as well as the shape of the light curve to select the Type II SNe candidates. We plan to take two spectra, at ~ 30 and ~ 60 days after turn on, respectively, of each Type II SNe to measure the expansion velocity of the photosphere looking at the redshift of the 5169 Å Fe line using the Palomar 200" telescope. We expect that once the search gets properly under way we will not be limited by the discovery rate but by the telescope time available for the follow-up spectra. We plan an initial study of 20 to 30 Type II SNe. At that time we will re-evaluate whether continuation to gather a larger sample is practical and/or worthwhile.

5. Strong Gravitational Lensing of Quasars

The gravitational lensing of quasars is sensitive to the cosmological parameters and thus the properties of dark energy. Since quasars are one of the brightest objects in the sky we can observe substantial numbers of them out to redshift 3 or 4, which is higher than for samples of objects expected in supernova or weak lensing studies. We are planning to carry out a statistical study of the lensing probability as a function of the quasar redshift. The sensitivity of the lensing probability to Ω_Λ and the equation of state parameter w are shown in Figures 3 and 4. If statistics were the only issue a sample of 100 lenses would yield a ± 0.04 measurement of Ω_Λ and a ± 0.2 measurement of w near their expected values of $\Omega_\Lambda \sim 0.7$ and $w \sim -1.0$. However, systematic uncertainties will dominate this measurement. We have carried out a detailed study of the systematic errors on such a measurement (C. Baltay, Roger Blandford, et al (2005) to be published). We find that the dominant uncertainty is the number density of the lensing galaxies. The galaxy number density as a function of the galaxy velocity dispersion has been measured by the SDSS collaboration recently for nearby ($z \leq 0.3$) galaxies. The remaining uncertainty is the evolution of the galaxy number density with redshift to $z \sim 1$ to 2, which are the relevant redshifts for lensing of quasars. We estimate that the present limits we can put on this evolution introduces an error of ± 0.14 on the Ω_Λ measurement. We thus conclude that strong lensing will not compete with the precision cosmological probes such as SNe Ia, CMB, or weak lensing, but it will provide another check, with very different systematics, on the Ω_Λ measurement. We feel that this measurement is important since the conclusion of an accelerating universe is of such a far reaching and unexpected nature that every possible check, with different approaches and systematic problems, should be performed.

In the Palomar QUEST Survey we will identify quasars both by color selection (using our seven colors, Johnson UBRI and Gunn riz) as well as yearly variability over a 5 year period. With our magnitude limit of 21 and a survey area of 15,000 square degrees we expect to find many hundreds of thousands of quasars. With the lensing probability of ~ 10^{-3} we should find a sample of ~ 100 lensed quasars. We will use the WIYN and the Palomar 200" telescopes for spectroscopic follow-up. We will pay careful attention to the determination of the size of the parent quasar sample and the lens detection efficiency which are crucial to the statistical measurement of the lensing probability (these quantities have not been well known for many of the previous strong lensing samples). In any case as a consolation prize we will be able to use the cosmological parameters determined from Supernovae, CMB, and weak lensing as input constraints and use our well studied sample of lensed quasars to learn about galaxy mass distributions, galaxy evolution, etc., which are also interesting questions.

We have just recently formed a collaboration with the group of Georges Meylan and Frederick Courbin, et al, of Lansanne, Switzerland. They have developed very advanced image deconvolution algorithms which will be important in the identification of lensed quasars. They will also have access to ESO telescope time in Chile for spectroscopic follow-up time which will be very valuable.

6. A Study of Intermediate Redshift Type Ia Supernovae

The Nearby Supernova Factory and the study of Type II SNe described above will use the supernova discovery (pixel level subtraction) programs developed by the SCP collaboration of Perlmutter, Aldering, et al. These programs will be run at Berkeley for the above two programs. A byproduct of this process will be several hundred Type Ia SNe in the redshift range of $0.1 \leq z \leq 0.3$. This is an interesting sample considering the gap in this region in the Hubble diagram of the Type Ia SNe. However, the spectroscopic follow-up of such a sample requires a considerable amount of large telescope time which we do not have available to our group at this time. Thus this project is on hold until we identify some collaborators with telescope time who are interested in following up this intermediate redshift supernova sample.

References

G. Aldering, et al, "The Nearby Supernova Factory", White Paper submitted to the Dark Energy Task Force, June 2005

C. Baltay, et al (2005) to be published

C. Baltay, Roger Blandford, et al (2005) to be published

Hamuy and Pinto (2002)< ApJ <u>566</u> L63

M. Graham, et al, "Palomar-QUEST: A Case Study in Designing Sky Surveys in the VO Era", 2004, in Proc. ADASS XIII

A. Mahabal, et al, "Exploring the Time Domain wit the Palomar-QUEST Sky Survey", in Wide-Field Imaging From Space, 2005

A. Mahabal, et al, "Time Domain Explorations with Digital Sky Surveys", in Proc. ADASS XIV, 2005

Table 1

Palomar-QUEST Science Projects

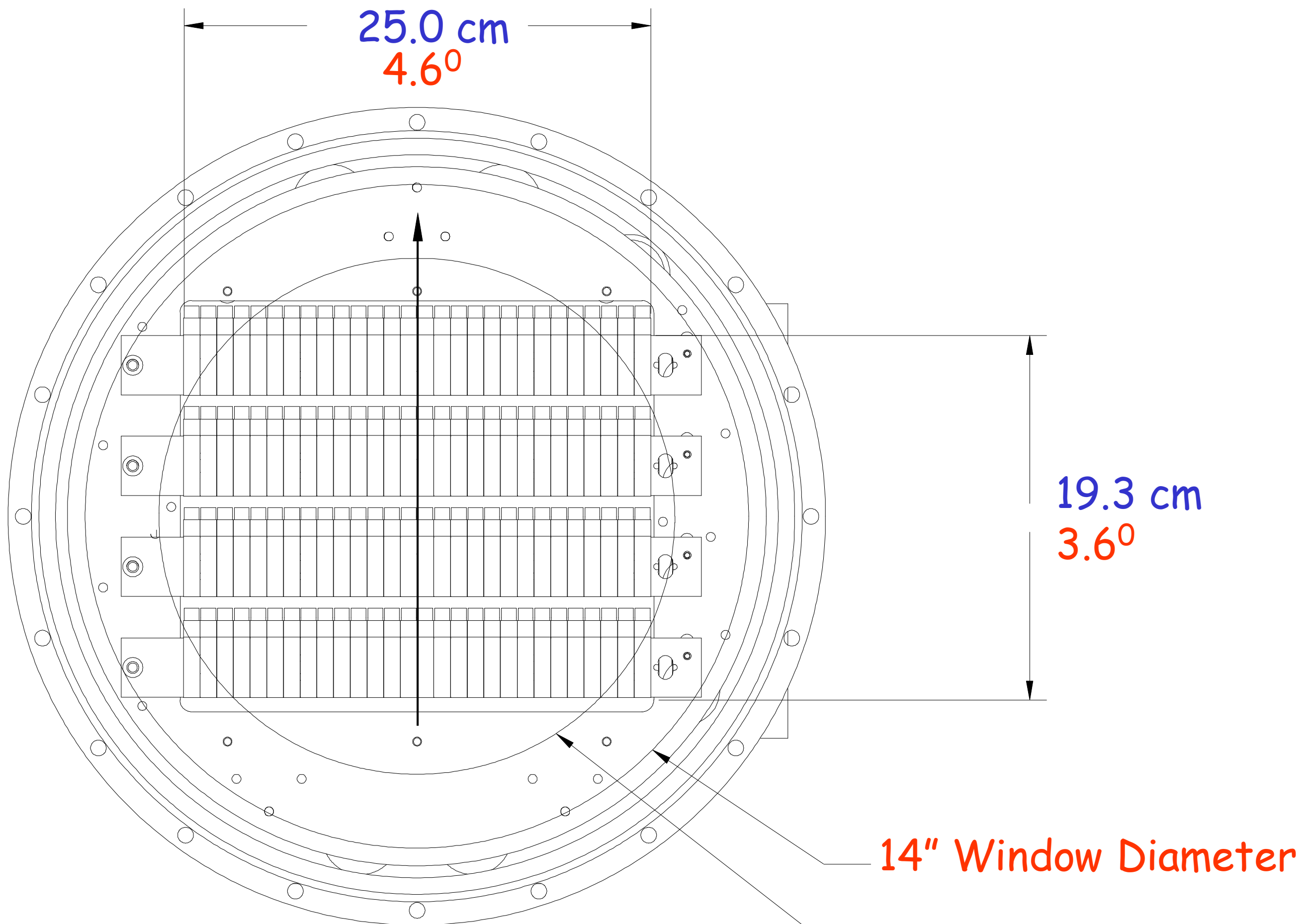
1. Quasar Variability Survey (~ 15000 sq degrees)
   Yale Group, University of Illinois
2. Gravitational Lensing of Quasars
   Yale Group
3. High Red Shift Quasars Z ≥ 6
   G. Djorgovski, et al., and Yale Group
4. Type Ia Supernova
   Perlmutter, Aldering, Nugent, Woods-Vasey, et al., with Yale Group (Supernova Factory)
5. Type II Supernova
   R. Ellis, Avishay Gl-Yam and Yale Group
6. GRB's, Tlype Ib,c Supernovae, Unusual Transients
   S. Kulkarni, et al., and G. Djorkovski, et at.
7. Minor Planet/Kuyper Belt Object Survey
   Mike Brown, et al., and D. Rabinowitz, Yale
8. RR Lyrae Stars
   Yale (Bob Zin, Kathy Vivas, et al.)
9. Near Earth Asteroid Tracking
   JPL NEAT Project
10. T-Tauri Stars
    Lynn Hillenbrand, John Carpenter, et al.
11. Young Star Formation
    Kent Honeycutt, et al.

Table 2

Properties of the Palomar-QUEST Instrument

Telescope	
Aperture Dia	1.2 m
Focal Length	3 m
Focal Ratio	2.5
Plate Scale	15μ/arc sec
CCD's	
Size	2400 x 600
Pixel Size	13μ x 13μ
Pixel in Arc Sec	0.87
Total No. of CCD's	112
Total Pixels	161 x 10^6
Area of Array	
Physical Array Size	19 cm x 25 cm
Physical Area of CCD's	273 cm^2
Array Size Degrees	3.6^o x 4.6^o
Total CCD Area, Sq Deg	9.3 sq deg
Scan Width	4.6^o
Filters	Johnson UBRI or Gunn rizz
Area Covered Per Night	500 to 700 sq degrees

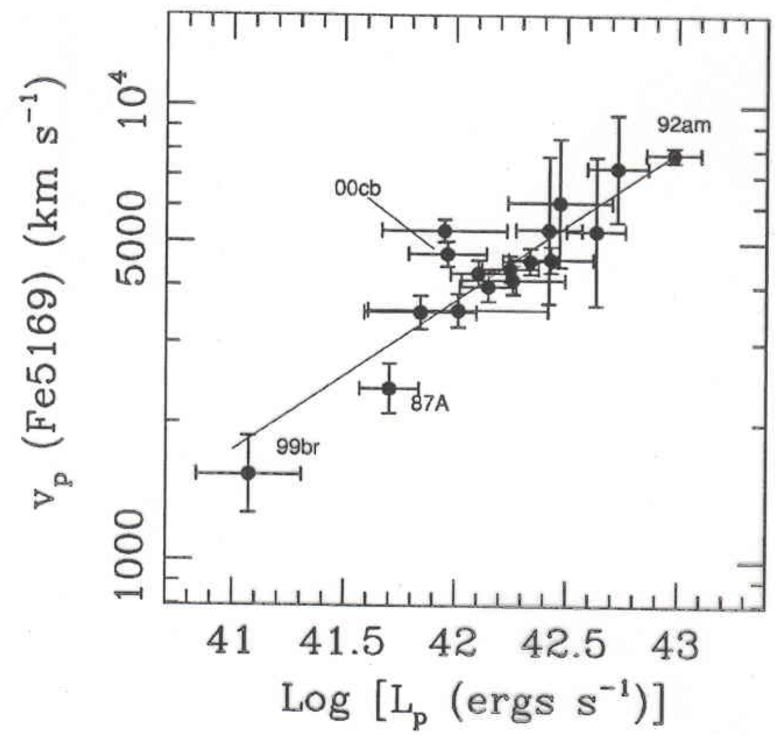
Large Area CCD Camera for the 48" Palomar Schmidt Telescope



4 Rows of 28 CCD's each ➡ 112 CCD's total
Each CCD – 2400 x 600 13 μ x 13 μ pixels
Array 16, 800 x 9,600 pixels ➡ 161 Megapixels tot.

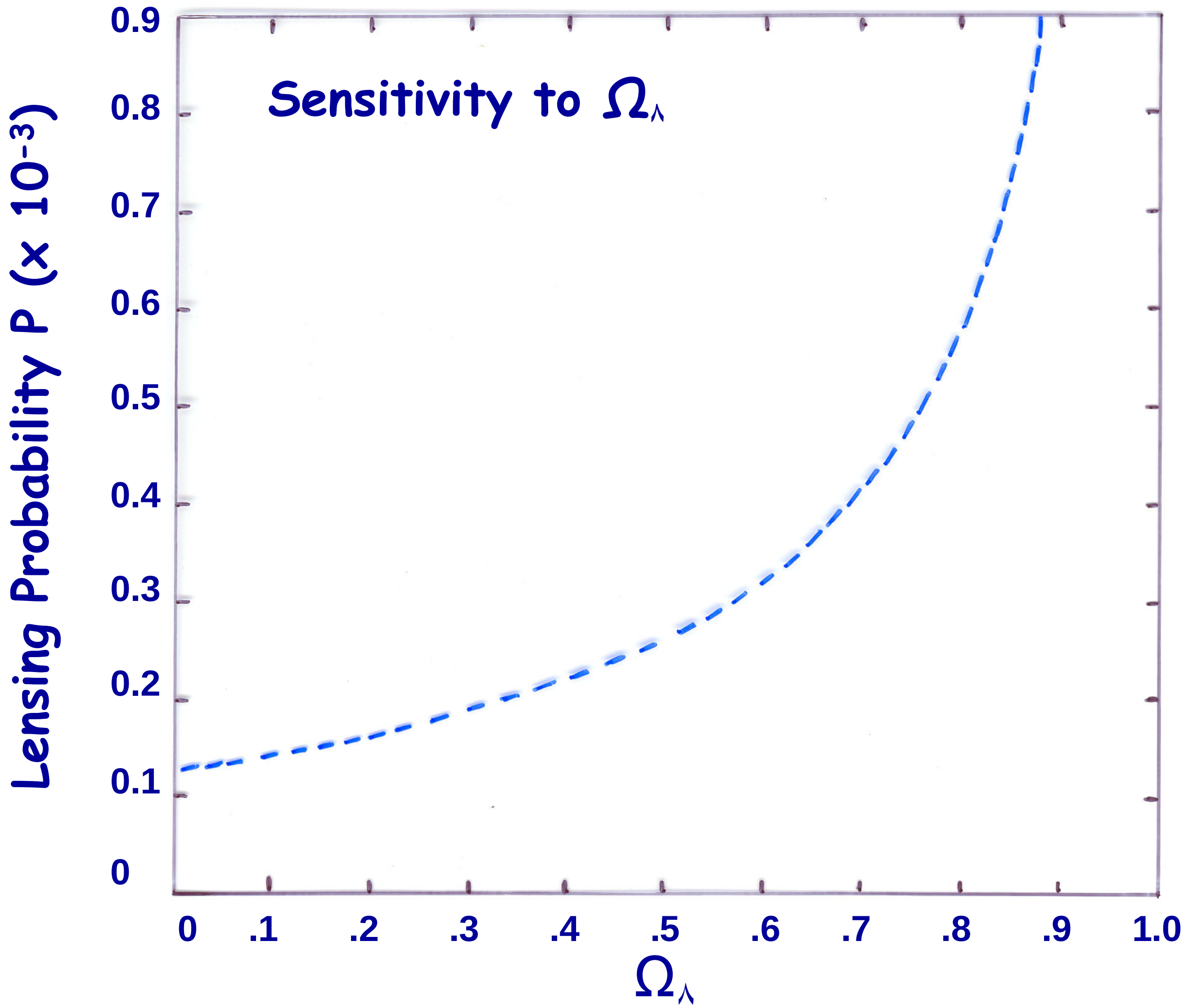
Figure 1

Hamuy & Pinto
ApJ 566 L63 (2002)



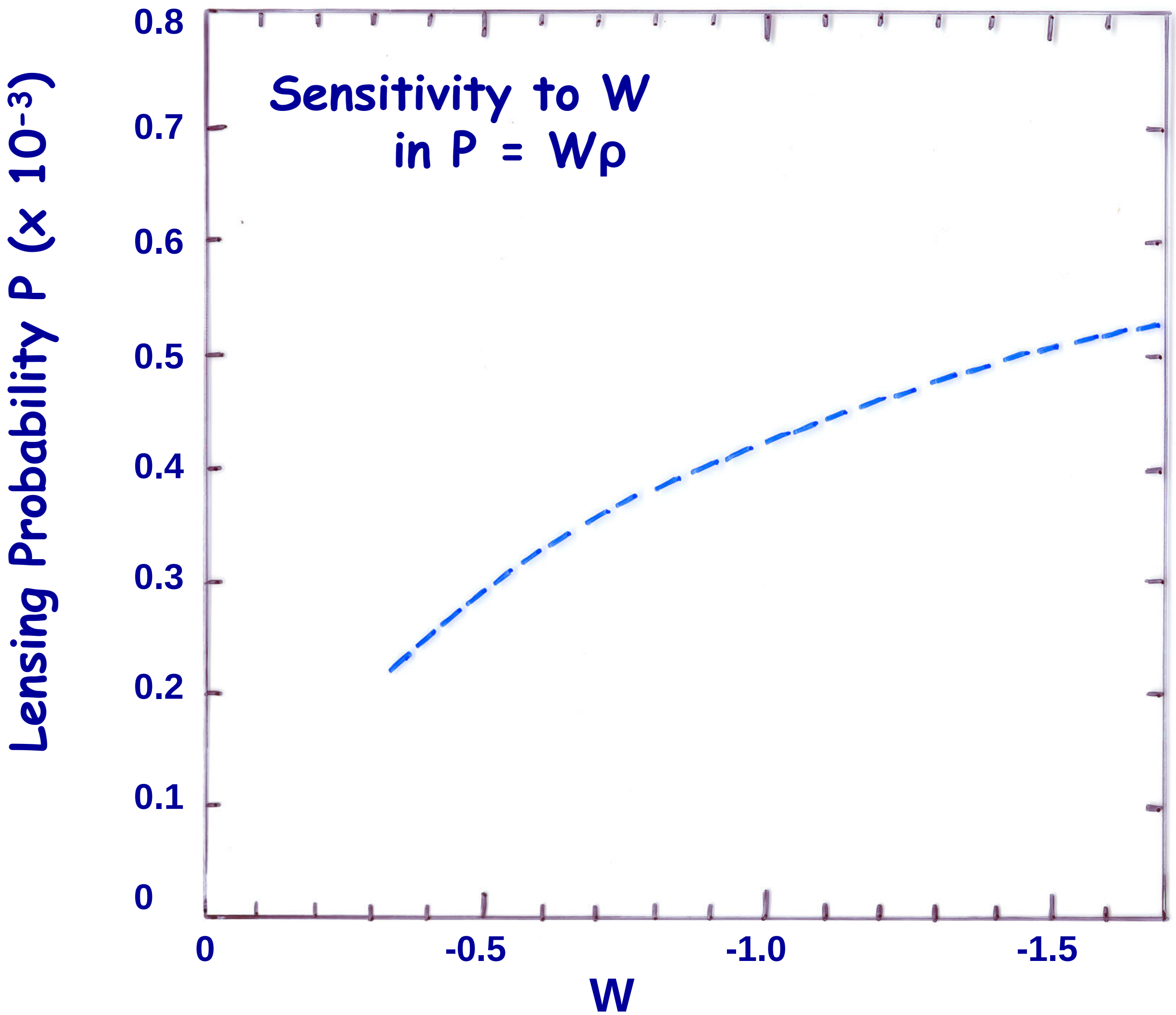
Correlation between peak luminosity L_p and expansion velocity of the photosphere, v_p, for Type II p Supernovae from Hamuy and Pinto (2002)

Figure 2



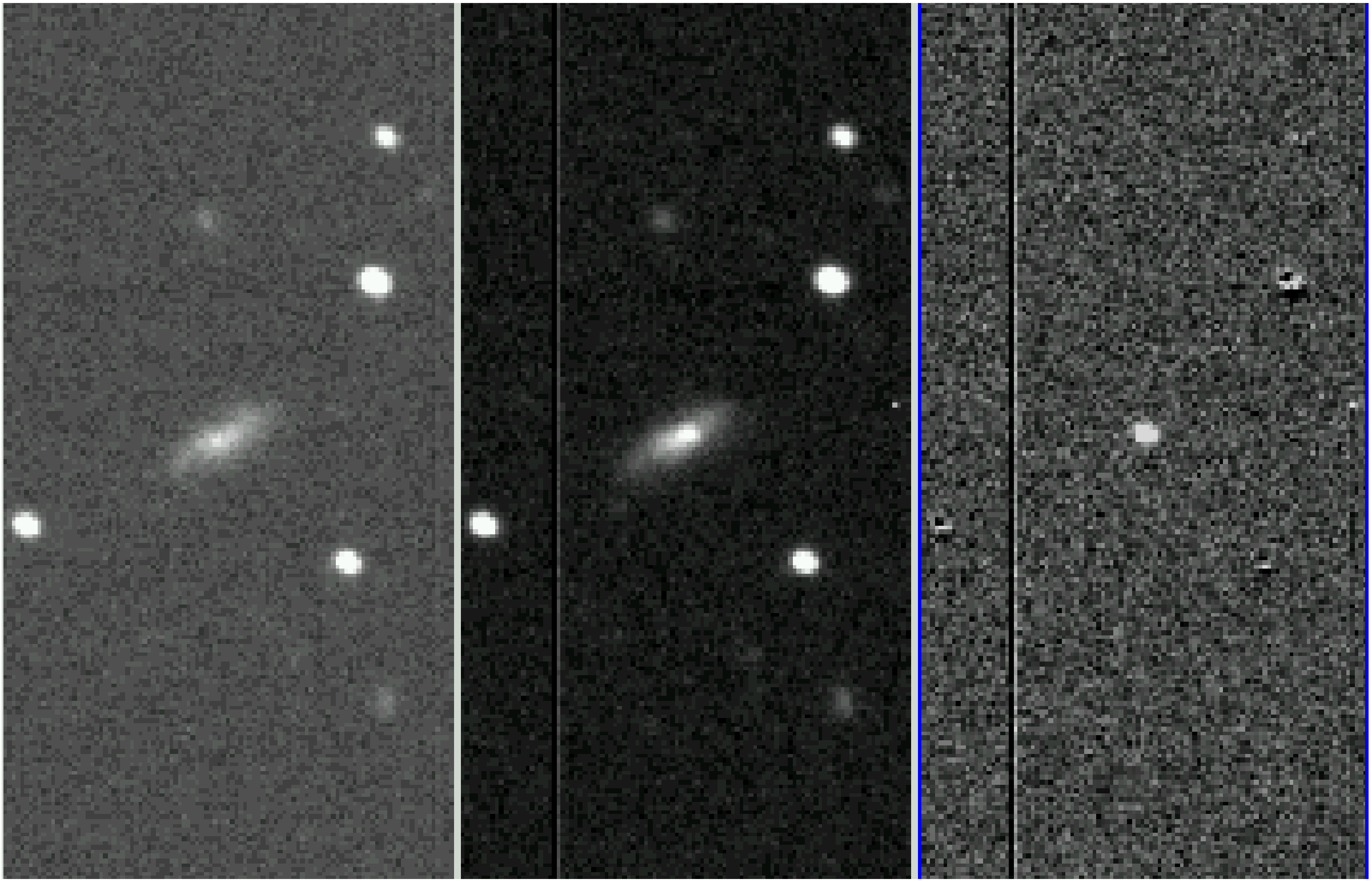
Sensitivity of the strong lensing probability of quasars to Ω_Λ.

Figure 3



Sensitivity of the strong lensing probability of quasars to the equation of the state parameter w.

Figure 4



Palomar-QUEST SNe 18 discovered by our SNe discovery program. The left hand panel shows the Reference scan taken April 21, 2004 with the background host galaxy before the SNe explosion. The central panel shows the Discovery scan, taken May 18, 2004, and the right hand panel shows the supernova from the Discovery scan with the reference scan subtracted pixel by pixel.

Figure 5